

CLAIMS

1 1. A lens system having an axis, comprising:
2 a first lens group having positive refractive power;
3 a second lens group positioned forward the first lens group along the axis
4 and having negative refractive power, the second lens group comprising one or more zoom
5 lenses;
6 a third lens group having positive refractive power and positioned forward
7 the first and second lens groups along the axis; and
8 wherein at least one zoom lens is movable along the axis, enabling a laser
9 transmitted through the lens system to be focused at different depths, such that the lens
10 system is capable of scanning a laser focused with a spot size of less than about 3 microns
 over a field having a diameter of at least about 9 mm at the different depths.

1 2. The lens system of claim 1, wherein the lens system has a nominal focal
2 length, and wherein the different depths to which the laser is transmitted through the lens
3 system may be focused using the one or more zoom lenses over a range from at least about
4 +1 mm to at least about -1 mm from the nominal focal length of the lens system.

1 3. The lens system of claim 1, wherein the lens system has a focal length, and
2 further comprising a fourth lens group movable between a first position along the axis and a
3 second position out of alignment with the axis, the fourth lens group in the first position
4 being placed between the second and third lens groups to increase the focal length of the
5 lens system.

1 4. The lens system of claim 3, wherein the lens system has a viewing field that
2 is increased to at least about 25 mm when the fourth lens group is in the first position.

1 5. The lens system of claim 3, wherein the lens system has a viewing field that
2 is increased to at least about 30 mm when the fourth lens group is in the first position.

1 6. The lens system of claim 3, wherein the lens system has a working distance
2 that is greater than about 100 mm when the fourth lens group is in the first position.

1 7. The lens system of claim 3, wherein the fourth lens group has negative
2 refractive power.

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1 8. The lens system of claim 6, wherein the fourth lens group comprises a lens
2 doublet.

1 9. The lens system of claim 1, wherein the lens system has a working distance
2 that is greater than about 36 mm.

1 10. The lens system of claim 1, wherein the lens system has a scanning field that
2 has a field flatness of less than about 10 microns.

3 11. The lens system of claim 1, wherein the laser is a femtosecond laser.

1 12. The lens system of claim 11, wherein the femtosecond laser is used in laser
2 eye surgery.

1 13. The lens system of claim 11, wherein the femtosecond laser is the Pulsion™
2 FS laser.

1 14. The lens system of claim 1, wherein the laser is employed to cut a flap in the
2 cornea of the eye.

1 15. A lens system having an axis, comprising:
2 a first lens group having positive refractive power;
3 a second lens group positioned forward the first lens group along the axis
4 and having negative refractive power, the second lens group comprising one or more zoom
5 lenses;
6 a third lens group having positive refractive power and positioned forward
7 the first and second lens groups along the axis; and
8 wherein at least one zoom lens is movable along the axis such that a laser
9 transmitted through the lens system may be focused over a range of depths while
10 maintaining diffraction-limited performance and a numerical aperture of at least about 0.3 at
11 a working distance of greater than about 36 mm.

1 16. The lens system of claim 15, wherein the laser transmitted through the lens
2 system can be scanned over a field having a diameter of at least about 9 mm over the range
3 of depths.

1 17. The lens system of claim 15, wherein the lens system has a nominal focal
2 length, and wherein the range of depths to which the laser is transmitted through the lens
3 system is at least about +1 mm to at least about -1 mm from the nominal focal length of the
4 lens system.

1 18. The lens system of claim 15, wherein the laser is a femtosecond laser.

1 19. The lens system of claim 18, wherein the femtosecond laser is the Pulsion™
2 FS laser.

1 20. The lens system of claim 15, wherein the lens system has a focal length, and
2 further comprising a fourth lens group movable between a first position along the axis and a
3 second position out of alignment with the axis, the fourth lens group in the first position
4 being placed between the second and third lens groups to increase the focal length of the
5 lens system.

1 21. The lens system of claim 20, wherein the lens system has a viewing field that
2 is increased to at least about 25 mm when the fourth lens group is in the first position.

1 22. The lens system of claim 20, wherein the lens system has a viewing field that
2 is increased to at least about 30 mm when the fourth lens group is in the first position.

1 23. The lens system of claim 18, wherein the lens system has a focal length, and
2 wherein the focal length is increased to greater than about 100 mm when the fourth lens
 group is in the first position.

1 24. The lens system of claim 15, wherein the lens system has a ratio of the
2 change in the depth of focus to the movement of the zoom lens that is close to 1 to 1.

1 25. A method of performing laser eye surgery, comprising:
2 focusing a laser with a lens system having at least one zoom lens to a
3 predetermined position in the cornea of an eye of a patient;
4 scanning the laser over a predetermined scanning path in the cornea to cut a
5 corneal flap in the eye,

6 wherein the scanning path includes a range of depths, and zooming the focus
7 of the laser at different depths is performed using the at least one zoom lens of the lens
8 system.

1 26. The method of claim 25, wherein the focused laser has a spot size of less
2 than about 3 microns.

1 27. The method of claim 25, wherein the scanning path is associated with a
2 scanning field having a diameter of at least about 9 mm.

1 28. The method of claim 25, wherein the cutting of the corneal flap comprises:
2 focusing the laser to a specific depth within the cornea;
3 delivering the laser to multiple spots positioned close together to form a
4 spiral pattern, creating an incision at the specific depth; and
5 creating a stack of arc-patterned paths about the periphery of the spiral
6 patterned cut by:
7 zooming the focus of the laser to different depths ranging from the specific
8 depth of the incision to the surface of the cornea.

1 29. The method of claim 28, further comprising:
2 increasing the focal depth and viewing field of the lens system so that the
3 focal depth and viewing field are sufficiently large to enable a magnified image of the
4 corneal flap of the eye to be viewed while having sufficient space between the lens system
5 and the eye to allow a surgical instrument or hand to manipulate the corneal flap.

1 30. The method of claim 28, wherein the cutting at the specific depth has a field
2 flatness of less than about 10 microns.

1 31. The method of claim 25, further comprising:
2 inserting a lens group within the lens system to allow viewing of the eye
3 through the lens system and increase the working distance of the lens system.

1 32. The method of claim 31, wherein the insertion of the lens group provides
2 sufficient space between the lens system and the patient's eye to allow manipulation of the
3 corneal flap with an instrument.

1 33. The method of claim 25, further comprising:
2 positioning a lens group within the lens system to allow viewing of the eye
3 and to increase the working distance of the lens system to greater than about 100 mm.

1 34. The method of claim 33, wherein the positioning of the lens group within the
2 lens system increases the viewing field to greater than about 25 mm.

1 35. The method of claim 34, wherein the positioning of the lens group within the
2 lens system increases the viewing field to greater than about 30 mm.

1 36. The method of claim 35, further comprising:
2 focusing the laser at a working distance of at least about 36 mm so that the
3 system of lenses will not interfere with the patient's nose.

1 37. The method of claim 25, wherein the lens system has a nominal focal length,
2 and wherein the range of depths to which the laser may be focused is from at least about +1
3 mm to at least about -1 mm from the nominal focal length of the lens system.

1 38. The method of claim 25, wherein the laser is a femtosecond laser.

1 39. The method of claim 38, wherein the femtosecond laser is the Pulsion™ FS
2 laser.

1 40. A lens system for use in laser eye surgery comprising:
2 a first lens group having positive refractive power;
3 a second lens group positioned forward the first lens group and having
4 negative refractive power and comprising a zoom lens;
5 a third lens group having positive refractive power and positioned forward
6 the first and second lens groups;
7 a fourth lens group movable between a position between the second and third
8 lens groups and a position away from the second and third lens groups such that when the
9 fourth lens group is positioned between the second and third lens groups, the focal depth
10 and viewing field of the lens system increases;
11 wherein the lens system is capable of: operating at a working distance of
12 greater than about 36 mm; scanning a field having a diameter of at least about 9 mm;

focusing a laser with a spot size of less than about 3 microns; and having a numerical aperture of greater than about 0.3 over the entire scanning field; and

wherein the zoom lens is movable along the principle optical axis of the lens system such that a femtosecond laser transmitted through the lens system may be focused at different depths ranging from at least about +1 mm to at least about -1 mm from the nominal focal length of the lens system.

41. A lens system, substantially satisfying the following chart:

Lens	Surface	r (mm)	t1 (mm)	t2 (mm)	N	V	d (mm)
L1	1	310.254	6.25 ± .05		1.62041 ±.0002	60.32 ±.01	63.91
	2	-865.592		.051 +.020 or - .05			63.94
L2	3	71.8605	9.75 ± .05		1.78831 ±.0002	47.47 ±.01	63.69
	4	278.115		8.260 ± .05			61.58
L3	5	-300.853	2 + .01 or - .042		1.66446 ±.0002	35.83 ±.01	58.22
	6	58.781		46.740 ± .05			55.70
L4	7	-71.835	24.361 + .010 or - .002		1.78831 ±.0002	47.47 ±.01	63.45
	8	-81.295		1.643 + .009 or - .041			75.66
L5	9	130.107	15.4 +.005 or -.025		1.62041 ±8.5e-5	60.32 ±.01	78.31
	10	-156.501		.051 +.006 or - .028			77.55

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L6	11	80.908	10.25 +.014 or -.05		1.66446 ±.0002	35.83 ±.01	71.42
	12	235.496		.035 +.015 or - .003			67.71
L7	13	41.666	16.8 + .037 or - .012		1.62041 ±.0002	60.32 ±.01	59.38
	14	-743.185	0.03		1.51680 ±.0001	64.17 ±.01	51.45
L8	15	-743.506	2.200 +.010 or -.046		1.78472 ±.0002	25.76 ±.01	51.41
	16	29.521		44 ± .05			40.62
L9	17	34.735	10.1				48.30
	18	45.15	11.003				44.0
L10	19	-72.12	2				42.4
	20	60.17	14				43.4

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wherein: r is the radius of curvature of an individual lens surface; t1 is the lens thickness; t2 is the aerial lens-to-lens distance; N is the refractive index of an individual lens; V is the abbe number of the lens glass; and d is the diameter of an individual lens surface.

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42. The lens system of claim 41, wherein tolerances associated with parameters of the lens system are substantially as shown in the following tables:

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Lens	Surface	r: Power (fringes)	r: Irregularity (waves)	surface decenter x (mm)	surface decenter y (mm)	surface TIR x (mm)	surface TIR y (mm)
L1	1	4	0.2	± .05	± .05	.005	.005
	2	4	0.2	± .05	± .05	.005	.005
L2	3	4	0.2	± .0071955	± .0071936	.005	.005

7		4	4	0.2	± .028266	± .028274	.005	.005
8	L3	5	3.5747	0.2	± .013228	± .013228	.0025716	.0025716
9		6	3.6417	0.2	± .029432	± .029432	.0028015	.0028015
10	L4	7	3.865	0.2	± .037273	± .037273	.0033586	.0033586
11		8	3.2172	0.2	± .0030108	± .0030109	.0028606	.0028606
12	L5	9	4	0.2	± .0058993	± .0059003	.0036413	.003642
13		10	2.9502	0.2	± .0042619	± .0042624	.0021763	.0021765
14	L6	11	4	0.2	± .011826	± .011826	.005	.005
15		12	4	0.2	± .014127	± .014128	.0041844	.0041846
16	L7	13	4	0.2	± .0026876	± .0026871	.0039213	.0039206
17		14	4	0.2	± .05	± .05	.005	.005
18	L8	15	4	0.2	± .003153	± .0031524	.0044445	.0044437
19		16	4	0.2	± .05	± .05	.005	.005

20	Lens	element decenter x (mm)	element decenter y (mm)	element tilt x (degrees)	element tilt y (degrees)
21	L1	± .05	± .05	± .019337	± .019333
22	L2	± .0080018	± .0079994	± .0057032	± .0057029
23	L3	± .0024825	± .0024825	± .0041356	± .004135
24	L4	± .014185	± .014186	± .029466	± .029466
25	L5	± .0024791	± .0024794	± .0049561	± .0049558
26	L6	± .013323	± .013323	± .003873	± .0038727
27	L7	± .0097664	± .0097667	± .0071825	± .0071814
28	L8	± .05	± .05	± .05	± .05

29 wherein TIR is the total indicator runout of a surface.